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V.—ARISTARCHUS OF SAMOS.[1]

A work by Sir Thomas Heath dealing with Greek mathematics may be sure of an appreciative circle of readers, fit though few. On the purely mathematical side the present reviewer could not hope to say much that would greatly concern either the author or his readers, even if a philological journal should be thought a suitable means of bringing it to their attention. But the author has done much besides giving us an admirable new edition of an interesting document for the history of Greek mathematical astronomy, which indeed forms a minor part of the present volume; he presents what may safely be called the best history of Greek astronomy and cosmology in any language. In his Preface Sir Thomas relates the genesis of his work, which is typical of the growth and extension of a true scholar's studies, once he has conscientiously begun the exhaustive consideration of a theme which, like all things human, looks backward as well as forward.

Of the scope of the treatise the title page gives an accurate description, except that it affords no hint of the detailed study contained in Ch. IV of Part II, "Later Improvements on Aristarchus's Calculations". Mention should be made also of Ch. XIX of Part I, "Greek Months, Years and Cycles", in which a useful summary is given of Ginzel's researches in Greek mathematical and technical chronology.

It is to our author's survey of Greek astronomy and cosmology that we naturally turn; and since it has been already said that the book is the best in its field, the reviewer may be pardoned if he now directs attention to a number of points at which he believes our author to be in error. There are many other matters on which the writer cannot agree with Sir

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[1] Aristarchus of Samos, the Ancient Copernicus. A History of Greek Astronomy to Aristarchus, together with Aristarchus's Treatise on the Sizes and Distances of the Sun and Moon, a New Text with Translation and Notes. By Sir Thomas Heath. Oxford, Clarendon Press, 1913. Pp. viii + 425.

Thomas and the historians generally, but some of these are of such importance and require so much discussion that they must be reserved for fuller consideration at another time. Here, therefore, minutiae will chiefly occupy the writer.

P. 7 our author says, "according to Hesiod, an iron anvil would take nine days to pass from the heaven to the earth, and again nine days from the earth to Tartarus". Of course the "iron" anvil is a mistake, the reference being to Theog. 722,

ἐννέα γὰρ νύκτας τε καὶ ἤματα χάλκεος ἄκμων κτλ.

But I have long wondered whether even *χάλκεος* is correct. One naturally thinks of Hom. Il. A 590 sq., where Hephaestus (*ὁ χαλκεύς*) is hurled from the divine threshold and after falling all day drops at nightfall on Lemnos. The difference in time may be accounted for by the changed location of the abode of the Gods, Olympus in the Iliad being presumably the mountain, later, as in the Odyssey, the outer heaven. But may not the Hesiodic parallel be a revision of the Homeric? In that case the smith's anvil would allude to Hephaestus, and we should then read *χαλκέος*, in Hesiod surely an allowable Boeoticism.

P. 9 instead of saying "as Hesiod *was* the first to call it", would it not be better to say "is"?

P. 24, n. 7 Heath's suggestion of *κεῖται* for *κινεῖται* should be attributed to Montucla; see Diels, Vorsokr.^{3} I. p. 20, l. 20 sq.

P. 26 Heath renders Hippol. Refut. 1. 6. 1. (Vorsokr.^{2} I. 14. 1) *λέγει δὲ χρόνον ὡς ὡρισμένης τῆς γενέσεως καὶ τῆς οὐσίας καὶ τῆς φθορᾶς*, "And in speaking of time he has in mind the separate (periods covered by the) three states of coming into being, existence and passing away". On this passage see Zeller IA, 232, n. 3. Zeller says the language is curious, perhaps corrupt. In order to understand it we should compare Diog. L. 8. 84 (Vorsokr.^{2} I. 29. 22) with regard to Hippasus, *ἔφη δὲ χρόνον ὡρισμένον εἶναι τῆς τοῦ κόσμου μεταβολῆς*, and Theophrastus on Heraclitus (Vorsokr.^{2} I. 58. 11) *ποιεῖ δὲ καὶ τάξιν τινὰ καὶ χρόνον ὡρισμένον τῆς τοῦ κόσμου μεταβολῆς κατά τινα εἱμαρμένην ἀνάγκην.* These passages show conclusively that both Heath's interpretation and Neuhäuser's, who regarded the words as a definition of time, are erroneous. The meaning is simply that Anaximander's theory implied the existence of time, since origination, existence, and decay are determinate, as each has a definite period set to it. On the same pages Heath gives the traditional rendering of [Plut.] Stromat. 2 (Vorsokr.² I. 13. 34 sq.), which I have several times attempted to set right; see On Anaximander (Class. Philol. VII), p. 229, n. 2 and On Certain Fragments of the Pre-Socratics (Proceedings of the Amer. Acad. of Arts and Sciences, XLVIII), p. 687. But our author apparently has never heard of my studies. Numerous other corrections which I have made from time to time are ignored, but I shall not repeat what I have said elsewhere.

P. 42 our author suggests *ἐνίους* for *ἔνιοι* in Aët. 2. 14. 4 (Vorsokr.² I. 19. 38) *ἔνιοι πέταλα εἶναι* [sc. *τοὺς ἀστέρας*] *πύρινα ὥσπερ ζωγραφήματα.* In Dox. Gr. Diels set off these words as possibly referring to other philosophers, not to Anaximenes. In Vorsokr. he refers them to Anaximenes, but questions *ἔνιοι.* It is more likely that we should read *ἔνια,* whether we supply *ἄστρα* or suppose an attraction to the predicate. That Anaximenes was intended is made highly probable by Vorsokr.² I. 20. 5, to which Diels referred in Dox. Gr. The passage is, however, somewhat blind, for *ζωγραφήματα* rather suggests the constellations (zodiac), while the meaning of *ἀστήρ* for Anaximenes is never clear. Apparently he distinguished between planets and fixed stars, though calling them all "stars". Heath, p. 43, concludes "that Anaximenes was the first to distinguish the planets from the fixed stars in respect to their irregular movements"; but this seems far from certain. If Burnet is right, as I believe he is, in regarding the "infinite worlds" of Anaximander as referring (at least in part) to the fixed stars, which are thus removed beyond our cosmos, the distinction here assigned as an innovation to Anaximenes is assured for his predecessor; but even more, the bare mention of *ἕσπερος* and *ἑωσφόρος* in Homer, whether or not they both refer to Venus, ought to give one pause. Furthermore, it seems certain, as I shall try to show elsewhere, that the solstices were well known from early times (indeed Heath himself finds them in Hesiod), and with the knowledge of them went for the early Greek scientists the distinction between the ecliptic (sun, moon and planets) and the equator (fixed stars). The 'dip' of the zodiac is a datum of prime importance to Greek cosmology, apparently from Anaximander onwards. But to pursue this topic would lead us too far. Suffice it to say, that if the knowledge of the distinction is assumed, many otherwise blind statements in regard to early Greek philosophers become intelligible.

P. 43 in rendering Aët. 2. 11. 1 (Vorsokr.^{2} I. 19. 34) our author, following Tannery, translates *περιφορά* with "rotation"; it is more probably "periphery" or "circle", a meaning which the word often bears. The same error recurs p. 233, *ἡ ἐσχάτη περιφορὰ τοῦ παντός*, where *περιφορά* means periphery). The whole passage, however (*’Αναξιμένης καὶ Παρμενίδης τὴν περιφορὰν τὴν ἐξωτάτω τῆς γῆς εἶναι τὸν οὐρανόν*), deserves to be reconsidered. Tannery and Heath make *τῆς γῆς* depend on *ἐξωτάτω*, which gives an acceptable sense, but (unless *οὐρανός* is here used in a special, technical meaning) one which is so trivial as to be hardly deserving of mention. It was certainly not the way in which Ps. Galen, Histor. Philos. 54 understood Theophrastus; for we read *’Αναξιμένης τὴν περιφορὰν τὴν ἐξωτάτην γῆν εἶναι*, which Zeller, IA, 247, n. 1, pronounces a *lapsus calami*. That there is an error of some kind in the latter passage is quite probable; however, it inclines me to think that Theophrastus meant something quite different from that which Tannery and Heath suppose. First of all we must probably omit the reference to Parmenides, whose name does not occur in the parallel account of Ps. Plutarch, and whose views were sufficiently different from those of Anaximenes, although he also regarded the circumference, like the centre, of the cosmos as solid. But I suspect that Theophrastus had in mind the statement of Aristotle De Caelo II. 13, 294 b 13 sq., respecting the reasons why, on the view of Anaximenes and others, the earth does not fall. The earth, though it rests on air, is said to be broad and to shut in the air beneath it, serving as a lid (*ἐπιπωματίζειν*): *διὰ γὰρ τὴν στενοχωρίαν οὐκ ἔχων τὴν πάροδον ὁ ἀὴρ μένει διὰ τὸ πλῆθος* (sc. *τῆς γῆς*). To make this scheme work heaven and earth must be practically coterminous. I need hardly say that in my opinion both Aristotle and Theophrastus grossly misrepresented the thought of Anaximenes.

P. 56 Heath renders *κενεμβατοῦντα* in Aët. 2. 24. 9 (Vorsokr.^{2} I. 43. 6) with "stepping on emptiness". This is of a piece with Burnet's version (Early Greek Philosophy^2, p. 135), who says that when the sun suffers eclipse, according to Xenophanes it "tumbles into a hole". What Xenophanes appears to have meant is that, since the sun is constituted of ignited vapor, when it is eclipsed, it is because it has entered a region where there is a void, that is to say, where there is a want of evaporation.

P. 61 our author discusses Heraclitus, fr. 120 Diels, and quite ignores the final words. Since it is a matter of some interest to science, I may refer to my explanation of this passage in my essay On Certain Fragments of the Pre-Socratics, p. 714 sq.

P. 66 instead of "The earth, he [Parmenides] said, was formed from a precipitate of condensed *air*", it would be better to speak of "vapor", which is commonly the meaning of ἀήρ in early Greek thought, as Burnet has rightly insisted. It is the typical meteoric process that is described. On the same page begins a rendering of Aet. 2. 7. 1 (Vorsokr.[2] I. 111, 5 sq.). On the whole the version is accurate; but I cannot accept Heath's interpretation of ἐπαλλήλους as applied to the wreaths or crowns of Parmenides's cosmological construction. Burnet, Early Greek Philosophy[2], p. 215 renders ἐπαλλήλους with "crossing one another", explaining in a note that ἐπάλληλος is opposed to παράλληλος. Proclus on Plat. Crat., p. 6. 25, shows that this interpretation is permissible. See also Donaldson, New Cratylus, p. 325, and Jebb on Soph. Antig. 57. Diels, in his review of Burnet, Deutsche Litteraturz. Dec. 5, 1908, Col. 3090 sq., disputes this interpretation; but Plato, Tim. 36 BC confirms it. I believe, moreover, that we should read περιπεπλιγμένας ἐπαλλήλους, not περιπεπλεγμένας, ἐπαλλήλους, as Diels prints. With this text, where περιπεπλιγμένας is my conjecture, the meaning is clear, and ἐπαλλήλους is reinforced by περιπεπλιγμένας. The close of the passage—and this is due not to the translator, but to the excerptor,—assumes a contrast between fire and aether, which is certainly false. This is due to the loose usage of early writers who equate 'aether' now with fire, now with air. The final test lies in the relative positions they occupy in the cosmos; for there is not a particle of evidence that Greeks ever assumed a different order than earth, water, air, fire, whatever embellishments they may otherwise have introduced. After Aristotle, who identified his fifth element with *αἰθήρ*, further confusion came into accounts of earlier thinkers.

P. 88 Heath writes: "Apparently connected with this theory of the two hemispheres is Empedocles' explanation of the difference between winter and summer. It is winter when the air (forming one hemisphere) gets the upper hand through condensation and is forced upwards (into the fiery hemisphere), and summer when the fire gets the upper hand and is forced downwards (into the dark hemisphere); that is, in the winter the fire occupys less than half of the whole sphere of heaven, while in summer it occupies more than half". This is an interpretation of Aët. 3. 8. 1 (Vorsokr.^{2} I. 163. 16) Ἐμπεδοκλῆς καὶ οἱ Στωικοὶ χειμῶνα μὲν γίνεσθαι τοῦ ἀέρος ἐπικρατοῦντος τῇ πυκνώσει εἰς τὸ ἀνωτέρω βιαζομένου, θερείαν δὲ τοῦ πυρός, ὅταν εἰς τὸ κατωτέρω βιάζηται. Diels explains that one is to supply τὸν ἥλιον, which was probably clearly indicated in the original context, with βιαζομένου, and refers for the Stoic view to Diog. L. 7. 151 τῶν δὲ ἐν ἀέρι γινομένων χειμῶνα μὲν εἶναί φασι τὸν ὑπὲρ γῆς ἀέρα κατεψυγμένον διὰ τὴν τοῦ ἡλίου πρόσω ἄφοδον . . . θέρος δὲ τὸν ὑπὲρ γῆς ἀέρα καταθαλπόμενον τῇ τοῦ ἡλίου πρὸς ἄρκτον πορείᾳ. Neither explanation appears to me satisfactory. Heath's view seems quite impossible, and the comparison instituted by Diels does not explain the mechanics of the process. For some years I have held it probable that the text is to be corrected by transposing τοῦ πυρὸς and θερείαν δὲ, when the passage reads simply, 'Winter comes about when the air (which the Greeks generally regarded as cold) gaining the upper hand (in the cosmic πόλεμος in which now one element, now another gets temporarily the mastery), the fire by the condensation (and consequent settling) of the air is forced upwards, and summer when (the fire) is forced downwards'. I communicated this suggestion to Diels, but he neglected it in his third edition.

P. 97 Heath correctly renders Aët. 3. 13. 1 sq. (Vorsokr.^{2} I. 237. 46) thus, "Others maintain that the earth remains at rest. But Philolaus the Pythagorean held that it revolves round the fire in an oblique circle in the same way as the sun and moon". P. 100, however, we read, "The earth revolves round the central fire in the same sense as the sun and moon (that is, from west to east), but its orbit is obliquely inclined; that is to say, the earth moves in the plane of the *equator*, the sun and moon in the plane of the zodiac circle. It would no doubt be in this way that Philolaus would explain the seasons". This is a strange construction to put on κατὰ κύκλον λοξὸν ὁμοιοτρόπως ἡλίῳ καὶ σελήνῃ, which must mean, if anything, just what Heath's version says. To be sure Heath's interpretation gives us sense where the text gives nonsense: but why should one take very seriously the spurious fragments and doxography of Philolaus?

P. 98 "Outside it is infinite void which enables the universe to breathe, as it were". Our author, like many others, has no conception of the meaning of the "cosmic breathing" of the Pythagoreans. For his information I may refer to my Antecedents of Greek Corpuscular Theories (Harvard Studies, XXII), pp. 137–140.

P. 105 our author seems to me to treat with too much respect Boeckh's suggestion, supported by goodly scholars, that the movement attributed by Philolaus to the fixed stars was the precession of the equinoxes. It may be true, if we conclude (as I think we must on all accounts) that "Philolaus" is a later forgery; but the discovery of the precession by Hipparchus is too well ascertained seriously to think of it in connection with earlier scientists. From De Caelo I. 3, 270 b 13 sq. it is evident that Aristotle had never heard of such a thing.

P. 124 "Democritus was the first to recognize that the earth is elongated, its length being 1½ times its breadth". This is a close rendering of Agathemerus I. I. 2 (Vorsokr.² I. 393. 10) but may mislead the reader. Agathemerus is a geographer and is speaking of the inhabited or inhabitable land, ἡ (οἰκουμένη) γῆ, although he does chance to say simply ἡ γῆ.

P. 125 In the translation of Hippolytus, Refut. I. 13. 4 (Vorsokr.² I. 360. 16) ἀκμάζειν δὲ κόσμον ἕως ἂν μηκέτι δύνηται ἔξωθέν τι προσλαμβάνειν, we have this curious phrasing, "A world is at its prime *so long as it is no longer* (italics mine!) capable of taking in anything from without". Of course the meaning is that its ἀκμή continues until such time only as it may no longer be able to take on anything from without—a case of cosmic nutrition, a variant of cosmic respiration!

P. 127 our author interprets [Plut.] Stromat. 7 (Vorsokr.² I. 359. 48 sq.) in such sort that Democritus is made to explain the origin of sun and moon by the theory of capture. This view is held also by Zeller, IA, 895 and by many others. The report is, however, unintelligent and in part corrupt. As Heath's rendering is at many points incorrect, I will give my own. "He says that sun and moon had a beginning. They move [this is faulty, as on any view φέρεσθαι should not refer to present conditions] singly [κατ' ἰδίαν: possibly κατ' ἀρχήν stood in the original, though πρότερον ἔτι would at first blush seem to militate against this view; however, the condition referred to in πρότερον ἔτι clearly lies before the real beginning of sun and moon as separate entities, as we shall see] having as yet no heat at all nor yet any brightness [λαμπροτάτην MSS: I have long read λαμπρότητα, a conjecture which Diels also proposes in Vorsokr.^{3}], on the contrary being in character like to that of the earth; for even earlier each of them had severally [κατ' ἰδίαν, which is probably the source of the previous κατ' ἰδίαν] been the raw materials of a cosmos, but subsequently as the circle of the sun increased in size the fire was enveloped in it". The assumption that a capture theory is here proposed rests on (a) κατ' ἰδίαν φέρεσθαι, (b) γεγονέναι γὰρ ἑκάτερον τούτων πρότερον ἔτι κατ' ἰδίαν ὑποβολήν τινα κόσμου, ὕστερον δὲ μεγεθοποιουμένου τοῦ περὶ τὸν ἥλιον κύκλου ἐναπολειφθῆναι ἐν αὐτῷ τὸ πῦρ. As to (a) this point has been already met. Even if we read κατ' ἰδίαν, it does not naturally imply that there was no relation between sun and moon or between them and the cosmos, as the subsequent use of κατ' ἰδίαν sufficiently shows. In regard to (b) we may note two points. First, ὑποβολήν τινα κόσμου, as γάρ shows, is intended to explain the facts mentioned in the preceding clause, and can therefore hardly mean the nucleus of a separate cosmos, but must characterize the matter, of which sun and moon were in due course made, as the bare potency of a world: in other words, speaking in the language of Democritus, they were constituted of atoms and void. Then the last clause harks back to the statement that at the beginning sun and moon were neither hot nor bright, and explains that as the circle of the sun increased, fire, which produces heat and light, became enveloped in it. In view of the general haziness of the report it remains in doubt whether "the circle of the sun" means the circle on which the sun is placed or the disc of the sun itself. The language, both here and in ἐναπολειφθῆναι ἐν αὐτῷ τὸ πῦρ suggests a close parallel to the sun of Anaximander; but there is no other evidence for such a view as regards the Atomists, and it would be idle to build upon this. I hope to have made it clear that the capture theory rests on a very insecure foundation.

P. 154 in the discussion of the whorls of Plato's cosmology in the Republic, our author is obsessed with the conception of 'spheres', of which there is no hint in Plato. The whorls are rings or bands, and not hemispheres, as he would have us think. The point would hardly be worth making, were it not for the fact that writers, ancient and modern, pretend to find spheres everywhere in Greek astronomy and cosmology whereas in fact 'spheres' played a small part before the time of Aristotle.

P. 160 sq. the discussion of 'right' and 'left' in the cosmos is altogether inadequate, and Heath's conclusion, p. 163, is untenable. The whole subject requires thorough treatment, which it has never received. That there were different directions in which the diviners faced in taking auspices appears to be certain; sometimes they faced north, sometimes south. Hence 'right' and 'left' referred now to east, now to west. So much can be proved beyond a doubt. What remains in doubt is just what determined the different position in orientation. If someone will answer this question it will do more than anything else to solve the endless riddles with which the subject abounds. A prime requisite is that in the investigation data referring to Greek and Roman practices should be kept strictly apart.

P. 186 sq. Heath discusses the vexed passage, Arist. De Caelo II. 13, 293 a 27 sq. He recurs to it, p. 273 sq., but does not seem to me to advance its interpretation. To my mind the explanation is simple. The sentence πολλοῖς δ' ἂν καὶ ἑτέροις συνδόξειε . . . ἀλλὰ μᾶλλον ἐκ τῶν λόγων is one of those spiteful parenthetical remarks of which Aristotle is extremely fond. There is no need to inquire who are meant, but it is obvious that Aristotle includes himself. With τῷ γὰρ τιμιωτάτῳ οἴονται προσήκειν τὴν τιμιωτάτην ὑπάρχειν χώραν κτλ. (l. 30 sq.) he resumes the main thought, reporting the doctrines of the Pythagoreans. The fact that he begins the following sentence (293 b) with ἔτι δ' οἵ γε Πυθαγόρειοι does not militate against this view; Aristotle suddenly recalls, as he begins a new point, that he has mentioned others besides the Pythagoreans, and makes haste to confine his report to the latter. Passages in which his carelessness in marking the lines of division between historical or quasi-historical statements and his own comments on them are too common in his works to occasion much surprise.

P. 189 our author says that Voss, De Heraclidis Pontici Vita et Scriptis, accepted Tannery's hypothesis regarding the relation of the alleged views of Hicetas to Heraclides. As a matter of fact, Voss published his treatise before Tannery, as the latter in a subsequent article in the Archiv für Gesch. der Philosophie acknowledged. They arrived at the same views independently.

P. 229 our author's comments on Arist. De Caelo II. 4, 287 a 11 sq. do not seem to touch Aristotle's meaning, which is clearly that, on the assumption that space is self-existent, a polygonal body revolving about its axis would with its projecting angles at one moment occupy space which would be left vacant the next, when the straight sides succeeded to them.

P. 314 there occurs a curious slip, "the Chaldaean Berosus, who flourished about 280 B. C., in the time of Alexander the Great". This is due to too much compression of data. Berosus lived, we are told, in the days of Alexander, but wrote his Babylonian History under Antiochus I Soter, to whom he dedicated it, presumably soon after his accession in 280 B. C.

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